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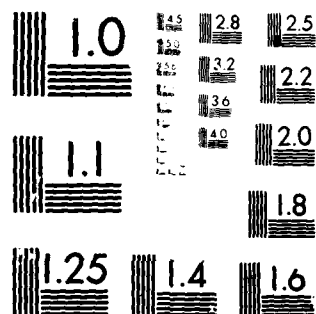
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In-House Report

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DIGITAL DIVERSITY COMBINER (DIDICOM) - AN APPLIQUE FOR OBTAINING QUADRUPLE DIVERSITY WITH DUAL DIVERSITY DRAMA RADIO TERMINALS

FREDERICK D. SCHMANDT

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diversity which should satisfy availability criteria and which does not entail any significant implementation technology difficulties. It is anticipated that this solution will be implemented on the English Channel link as part of the Digital European Backbone (DEB) Stage III implementation phase.

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SECTION 1

INTRODUCTION

1.0 Background

The AN/FRC-() () radio, being procured under the Digital Radio And Multiplex Acquisition (DRAMA) program, contains dual space or dual frequency diversity provisions: no additional diversity capabilities are provided.

The presently implemented Scope Communication microwave link across the English Channel between Swingate, England and Houtem, Belgium utilizes an unusual quadruple diversity system entailing both space and frequency diversity.^{1,4} The transition of this link to digital operation is scheduled to occur during the Digital European Backbone (DEB) Stage III Upgrade program. Diversity considerations prevent a direct replacement of the existing equipments with DRAMA equipments. The Rome Air Development Center (RADC) was tasked under a Memorandum of Agreement (MOA) with the DEB System Program Office (SPO) to investigate the problems entailed in the digital transition of the link and to provide a recommended approach. This report describes the results of the tasking.

The Swingate-Houtem link is the only one within the DEB microwave upgrade program which has in excess of dual diversity. Consequently one does not have the luxury of amortizing developmental costs of a solution for this link over a large production procurement. Major modifications to the DRAMA radio design configuration would be very costly. Thus in considering alternatives an effort was made to obtain an approach which entailed a minimal amount of change to the DRAMA radio design and which does not entail significant development problems. From the alternatives

considered, the use of an applique device of the type to be described was selected. The technology for such a device is readily available.

1.1 Overview of Report

As a point of departure Section 2 describes the present analog English Channel link and the theory upon which the system design is based. In transitioning from analog to digital operation, the easiest method would be to simply operate with a dual diversity DRAMA radio. The acceptability of such a procedure is addressed in Section 3: DCA established link availability criteria^{2,3} along with the parameters of the existing link are used to evaluate the feasibility of dual (space or frequency) diversity DRAMA radio operation. The substantial deficit predicted between the required and expected fade margins when using these criteria leaves no doubt DRAMA dual diversity operation would yield inadequate performance and also indicates the amount of improvement required.

Having shown a straightforward DRAMA radio application will not meet requirements, Section 4 describes an applique which, when used in conjunction with DRAMA radio terminals, would yield a digital configuration operationally similar to the present analog configuration which has been operating satisfactorily for a number of years. As will become clear the applique device is essentially a Digital Diversity Combiner, explaining the coining of the acronym "DIDICOM" which henceforth will be used. Section 4 addresses not only the conceptual DIDICOM approach but also operational interface requirements such as interfaces with multiplexer and Fault Alarm System (FAS) equipments.

In Section 5 previously obtained English Channel link data is used in concluding that the recommended DIDICOM approach will permit a

satisfaction of DCA link availability requirements. The section also identifies and briefly discusses the alternative approaches investigated during the study presenting reasons for rejecting such alternatives in favor of the DIDICOM approach.

SECTION 2

PRESENT ENGLISH CHANNEL LINK DESCRIPTION

2.0 Introduction

A description of the existing FDM/FM microwave link across the English Channel between Swingate, England and Houtem, Belgium may be found in reference 1 or 4. This section extracts certain aspects of the descriptions salient to this report and amplifies upon the transmission media phenomena theory upon which the existing system design is based.

2.1 Equipment Configuration

A block diagram of the present equipment configuration is shown in Figure 2.1. The system utilizes the LC-4SC quadruple diversity FM radio equipment. The rf carrier signals at Houtem are transmitted and received by a combination of four shrouded, plane-polarized parabolic antennas (two 15-foot and two 12-foot) vertically-spaced on an 800-foot tower structure. The transmit carriers, 4.908 GHz and 4.5465 GHz, are transmitted as follows: transmitters A and B are connected to the first and second 15-foot diameter antennas (starting at the top of the structure), respectively, and operate on 4.908 GHz in a hot-standby configuration. Transmitters C and D are connected to the fourth and third (from the top of the structure) 12-foot diameter antennas, respectively, and operate on 4.5465 GHz, also in a hot-standby configuration. Under normal operation, transmitters A and C function as the primary transmitters providing the selection of an upper and lower antenna on the tower for the transmission of two frequencies. Transmitters B and D are not placed on-line except when power detection monitoring circuitry in the respective transmitter rf output leg detects a loss of rf power or a power reduction beyond a

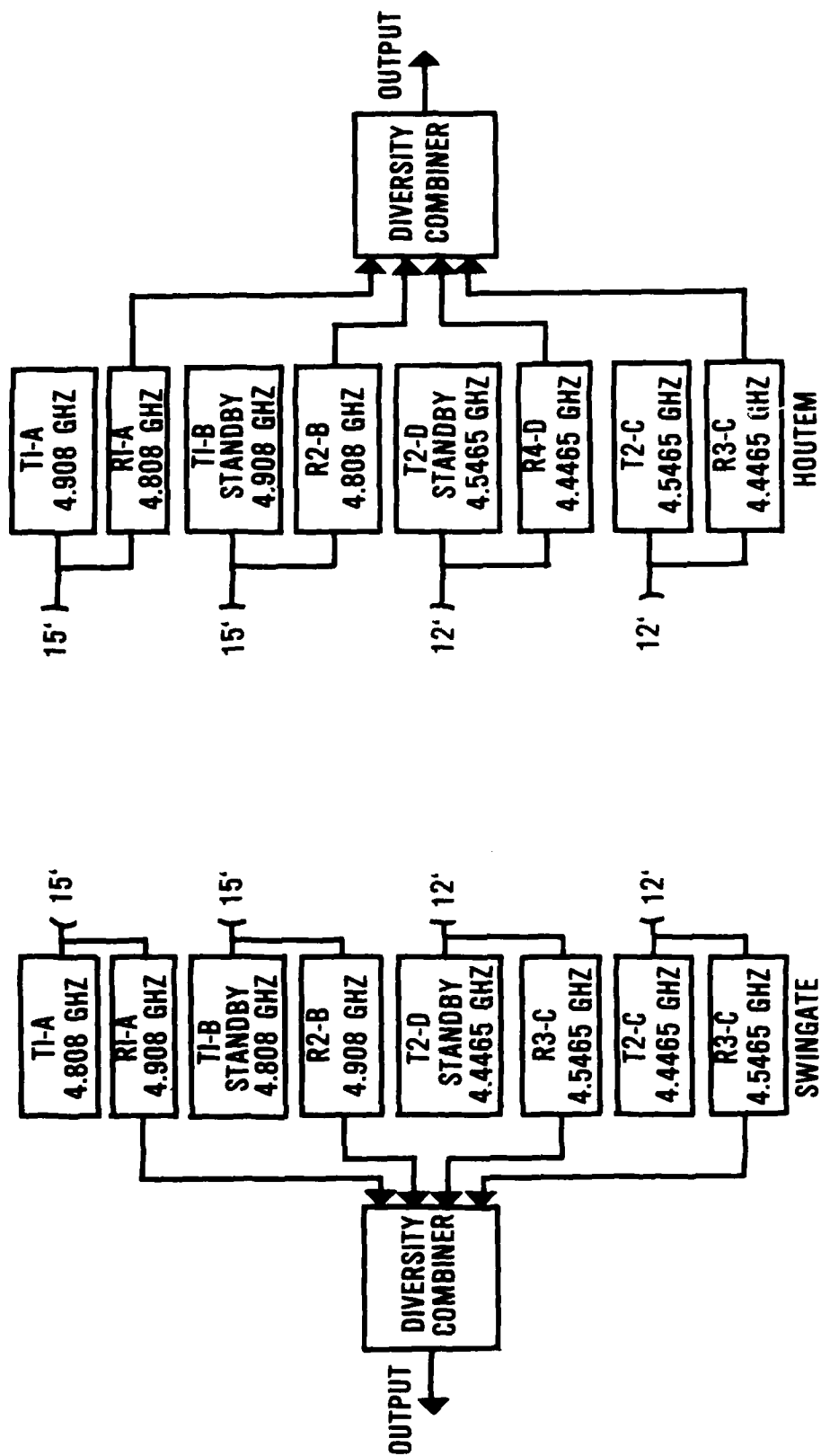


FIGURE 2.1: EQUIPMENT CONFIGURATION

prescribed level.

The received carriers from Swingate, 4.808GHz and 4.4465GHz, are received as follows: the 4.808GHz signal is received on the A and/or B receiver(s), depending upon propagation conditions, with the A receiver (together with the A transmitter) connected via an rf circulator to the top 15-foot diameter antenna, and the B receiver (together with the B transmitter) connected via an rf circulator to the second 15-foot diameter antenna. The 4.4465 GHz signal is received on the C and/or D receiver(s) which, as stated above, are connected to the fourth and third antennas (from the top of the structure) respectively.

The present analog system then uses a form of quadruple input maximal ratio squared combining, with low level signal squelching as described below. Each receiver output noise level is measured in an out of band noise slot above the 2.6 MHz maximum baseband frequency. The level of the noise in each channel is compared and the variable gain amplifiers included in series with each receiver are adjusted in inverse proportion to the square of the noise power appearing in that channel. The four receiver outputs are combined through differential amplifiers which produce a constant amplitude output signal. A squelch circuit is included in each receiver leg which is adjusted so that if the receive level is less than -55 dBm in any receiver its output is suppressed. If all four receivers are below this threshold the squelch is disabled. The receiver FM threshold is -79 dBm, well below the suppression level.

The equipment configuration at Swingate is identical to the configuration at Houtem. Applicable frequencies are as indicated in

Figure 2.1.

2.2 Theory of Operation

The existing link is not based upon conventional quadruple diversity system design principles. The width of the English Channel necessitates a long, 88 km (55 mile), line-of-sight, over-water path. Figure 2.2 depicts the link geometry. Lack of adequate terrain heights at the end points necessitates the use of high towers to obtain path clearance for $k = 2/3$, particularly at Houtem. The placement of the Swingate tower on the Dover Cliffs reduces the tower height requirement in comparison to the 800-foot structure at Houtem; nevertheless a 358-foot structure is still used. Long waveguide run length requirements, necessitated by the antenna heights from ground level, result in substantial losses. When these losses are combined with the well known losses associated with long, line-of-sight, over-water paths⁵ it is evident that the link design required special care.

In the implemented design the top most diversity antenna pairs correspond to a normal hot standby space diversity arrangement and provide operation under normal propagation conditions. These pairs provide protection against atmospheric multipath and sea surface reflections. However, ducting also presents significant problems on links of this type. Temperature and humidity inversions on sea paths tend to induce ducting conditions which can trap microwave signals and produce significant fading. The heights of the upper antennas place them above most of the ducting gradients predicted on the path thereby minimizing the susceptibility of the path to these anomalies. (Prediction is based upon refractivity data obtained from the USAF Environmental Technical Applications Center (ETAC)

HEIGHTS ABOVE MEAN SEA LEVEL (METERS)

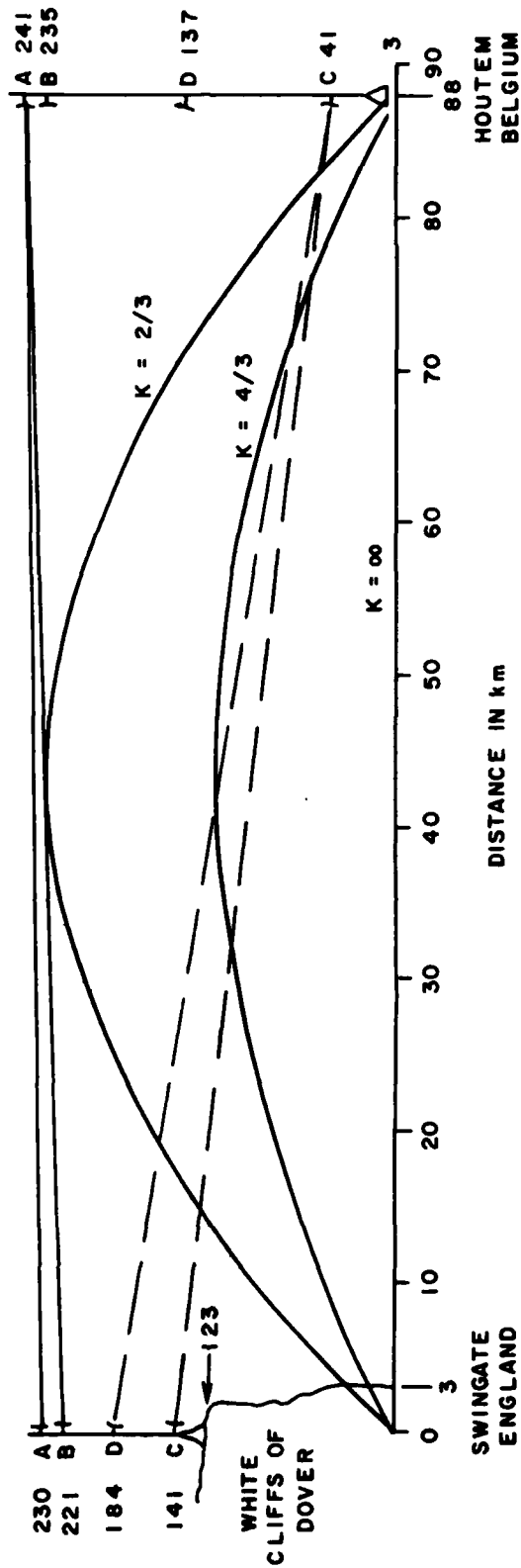


FIGURE 2.2: LINK GEOMETRY-HOUTEM TO SWINGATE

data which is summarized in Table 2 of reference 1). In spite of this minimization, initial measurements showed link performance to be unacceptable with just dual diversity operation. Thus the lower paths were established. Under normal propagation periods, these paths are obstructed, but during those conditions when energy in the upper pair is trapped in a duct, the duct tends to establish diffraction transmission paths to the lower antennas. In the present design, the lowest path is intended to provide transmission during low level ducts and the other low path is intended to accommodate more elevated duct formations. Placement of the antennas was selected somewhat arbitrarily, to attempt to obtain a link which satisfied requirements within a short time period. When satisfactory operation was obtained with the selected placement no attempt was made to obtain a more optimal arrangement. Link tests which verified the effectiveness of the implemented design were conducted over a period from October 1973 to April 1974 and are reported upon in reference 1. To provide more engineering detail, Air Force Communications Service (AFCS) conducted an additional test program to measure received signal levels (RSL's) on the quad-diversity system from July 1974 to May 1975. The unpublished results of the latter test program, some of which will be presented in Section 5, further verified the system design concepts. Overall the experimental data evaluated showed the quadruple space/frequency diversity system met or exceeded the expected performance and thereby verified the viability of the placement of antennas in the diffraction region. Simultaneous RSL measurements demonstrated that the lower diversity antenna paths are established during the times they are most needed, when energy in the

upper pair decreases. However, these same measurements indicated the upper of the lower two antennas was never required to carry data because when its RSL exceeded other channels their RSL was also large enough for effective transmission. This indicates a movement of the upper of the two lower antennas should not hamper performance and may actually improve conditions. This point will become important when it is shown in section 4 that an antenna movement is required to establish compatibility with the DRAMA space diversity radio terminal.

SECTION 3

DUAL DIVERSITY DRAMA RADIO PERFORMANCE

3.0 Introduction

Since the DRAMA radio is a dual diversity (space or frequency) terminal, if dual diversity digital operation could meet DCA performance criteria a straightforward digital transition could be accomplished. At the onset of this investigation, it was felt based upon the analog system experience that dual diversity would be inadequate. That was the very reason why the investigation was initiated.

In this section expected dual diversity DRAMA performance is investigated based upon the criteria of reference 2. This can be done by recourse to link parameters rather than by requiring test data; hence one need not worry about the validity of measurements. The required and expected fade margins for dual space and frequency diversity operation will be established and the results compared. The comparison not only demonstrates that dual diversity DRAMA radio operation would fail to yield acceptable performance but also indicates the amount of improvement required to satisfy established availability criteria.

3.1 Link Parameters

The present link parameters relevant to the calculations are given below:

- a. Path Length - 55 miles
- b. Transmit Frequencies (Swingate) - 4.808 GHz, 4.4465 GHz
- c. Transmit Frequencies (Houtem) - 4.908 GHz, 4.5465 GHz
- d. Waveguide (EW44) Length (Swingate) - 494 feet (Upper antennas)

- e. Waveguide (EW44) Length (Houtem) - 846 feet (Upper antennas)
- f. Antennas (Upper) - 15-foot Shrouded Plane Polarized Paraboloids.
- g. Antenna Separation - 30 feet.

3.2 Dual Space Diversity Operation

3.2.1 Required Fade Margin Dual Space Diversity

The required fade margin is obtained by using equation (1) of reference 2 with $P_0 = 3.5 \times 10^{-6}$. This equation can be rewritten as follows:

$$P_0 = N \times 10^{-F/5} \quad (3.1)$$

where

$$N = \left(r^2 + \frac{1}{r^2} \right) \frac{acD^4}{56S^2} \quad (3.1a)$$

and the notation used is identical to that used in reference 2. Solving equation (3.1) for F yields

$$F = -5 \log P_0 + 5 \log N \quad (3.2)$$

The following assumptions were made in performing the calculations:

a = $\frac{1}{2}$ (The fading season is 6 months long)

c = 1 (This value is obtained by taking the product of the factors $\frac{1}{2}$ for temperate or northern areas and 4 for over water - factors obtained from reference 6).

Equation (3.2) was evaluated with the indicated value of P_0 and the link parameters listed in Section 3.1 for diversity combiner hysteresis ratios of 0⁺, 1, 2, 5 and 10 dB. The results are:

$$F|_{0^+} = 38.6 \text{ dB}$$

$$F|_1 = 38.6 \text{ dB}$$

$$F|_2 = 38.8 \text{ dB}$$

$$F|_5 = 39.3 \text{ dB}$$

$$F|_{10} = 42.1 \text{ dB}$$

The proposed switch algorithm for the DRAMA radio described in reference 9 utilizes both received signal level (RSL) and the DRAMA signal quality monitor (SQM). The first comparison is of SQM's, and RSL's are not used unless the difference in SQM's is small. Thus the hysteresis value is not fixed but should be small. As discussed in reference 8, a small hysteresis is essential to maintain a reasonable diversity improvement factor under Rayleigh fading conditions. Additionally, as noted in reference 7 and further discussed in reference 8, loss of bit count integrity (BCI) can result if diversity selection is made when a large differential exists in the RSL's. In view of the above, the use of a large hysteresis ratio would be ill-advised. For performance comparison purposes a ratio of ≤ 1 dB will be assumed which means the required fade margin is 38.6 dB. Note, this is the smallest required fade margin obtainable for the existing link parameters and assumes the most favorable switch arrangement.

3.2.2 Expected Fade Margin Dual Space Diversity

The expected fade margin will now be calculated using equation (8) of reference 2. The equation can be rewritten as

$$F = G_{at} + G_{ar} + G_s - L_{fs} - L_w - L_m \quad (3.3)$$

The following parameters were extrapolated from reference 10 for EW44 waveguide and 15 foot parabolic antennas, respectively:

$$L_w (4.808 \text{ GHz}) = 1.16 \text{ dB/100 feet}$$

$$L_w (4.908 \text{ GHz}) = 1.13 \text{ dB/100 feet}$$

$$G_{at} (4.8 \text{ GHz}) = G_{ar} (4.8 \text{ GHz}) = 44.3 \text{ dB}$$

$$G_{at} (4.9 \text{ GHz}) = G_{ar} (4.9 \text{ GHz}) = 44.4 \text{ dB}$$

The system gain, G_s , is the difference between the power output of the transmitter, as delivered to the transmit waveguide, and the sensitivity of the receiver as measured at its interface with the receive waveguide. As delineated in reference 2, the receiver sensitivity of interest is the receiver strength required to meet the threshold bit error rate of 10^{-4} . To obtain this value, it is necessary to refer to the DRAMA specification. For level II operation, the specification ¹¹ requires:

$$RSL = -141 + 10 \log R \text{ for BER } \leq 5 \times 10^{-9}$$

$$RSL = -148 + 10 \log R \text{ for BER } \leq 5 \times 10^{-2}$$

With the DRAMA multiplexing technique, R equals 26.112 Mbps for the 384 channel configuration. Using the formula with this rate yields

$$\begin{aligned} \text{and } RSL|_{5 \times 10^{-9}} &= -66.8 \text{ dBm} \\ RSL|_{5 \times 10^{-2}} &= -73.8 \text{ dBm} \end{aligned}$$

With a linear interpolation

$$RSL|_{10^{-4}} = -72.3 \text{ dBm}$$

For the DRAMA specified power output of 33 dBm, the system gain

$$G_s = 33 - (-72.3) = 105.3 \text{ dBm}$$

Because the links have different transmitter frequencies the expected fade margin calculations differ. The free space loss is given (ref 2, page 39) by:

$$L_{fs} = 97 + 20 \log f + 20 \log D \quad (3.4)$$

So

$$L_{fs} \text{ (Swingate-Houtem)} = 97 + 20 \log 4.808 + 20 \log 55 = 145.4 \text{ dB}$$

$$L_{fs} \text{ (Houtem-Swingate)} = 97 + 20 \log 4.908 + 20 \log 55 = 145.6 \text{ dB}$$

The waveguide losses are:

$$L_w \text{ (Swingate-Houtem)} = (1.16) (4.94 + 8.46) = 15.5 \text{ dB}$$

$$L_w (\text{Houtem-Swingate}) = (1.13) (4.94 + 8.46) = 15.1 \text{ dB}$$

The only remaining value required to evaluate equation (3.3) is L_m . As per reference 2, the value of 6 dB is assumed. By substituting the above values, the expected fade margins obtained are

$$F (\text{Swingate-Houtem}) = 27.0 \text{ dB}$$

$$F (\text{Houtem-Swingate}) = 27.4 \text{ dB}$$

3.2.3 Predicted Deficit for Dual Space Diversity

Based upon the above calculations, a required fade margin of 38.6 dB exists under favorable diversity switch conditions. The expected fade margins are 27.0 dB and 27.4 dB for the Swingate to Houtem and Houtem to Swingate links, respectively. Consequently, link deficits of 11.6 dB and 11.2 dB are calculated for dual space diversity DRAMA radio operation. These deficits might be reduced somewhat if the implemented DRAMA radio performs better than the specification requires. Even so, a substantial deficit would still remain.

3.3 Dual Frequency Diversity Operation

3.3.1 Required Fade Margin Dual Frequency Diversity

The calculations for dual frequency diversity differ from those for dual space diversity only in the value used for S^2 in equation (3.1a).

For frequency diversity

$$S^2 = \frac{70 \times \Delta f}{f^2} \quad \text{in the 4GHz band}$$

Using this factor to obtain N and then using the calculated value of N in equation (3.2) the required fade margin for dual frequency diversity is obtained. Performing the above with a hysteresis of 1 dB or less yields:

$$F (\text{Swingate-Houtem}) = 34.5 \text{ dB}$$

$$F (\text{Houtem-Swingate}) = 34.6 \text{ dB}$$

3.3.2 Expected Fade Margin Dual Frequency Diversity

Expected fade margin calculation procedures set forth in reference 2 are the same for space and frequency diversity. On the surface it would therefore seem that a frequency diversity arrangement using the presently assigned frequencies would have an approximate 4 dB advantage, the difference between the above calculated required fade margin and the value of 38.6 dB calculated for space diversity. However, the formulation of the procedure for calculating the expected fade margin is not entirely valid for the English Channel link because of the extreme waveguide run lengths entailed. The attenuation difference in EW 44 waveguide results in approximately 3 dB more loss at the lower frequency assignments. Coupled with about a 0.5 dB loss for each antenna and 0.5 dB more free space loss, the lower frequency should result in about 4.5 dB more loss than the upper frequency. Consequently much of the apparent advantage in dual frequency diversity operation would be lost. Comparable performance is anticipated for dual space or frequency diversity.

3.4 Modification to Performance Predictions

Reference 3 details procedures whereby LOS digital radio links can be engineered to meet the performance requirements defined and developed in reference 2. The procedures for determining the required minimum fade margin are a function of path length. Furthermore the parametric values listed in reference 3 differ somewhat from those used in the preceding calculations. For example, the system gain calculated above and used in the expected fade margin calculations was 105.3 dBm whereas the number identified in the reference document for the DRAMA Level II system gain is 104 dBm. Using the values and procedures set forth in reference 3, supplemented by

the link parameters, deficits in excess of 15 dB are obtained. Consequently, the newer procedures result in the prediction of an even larger deficit.

3.5 8 GHz Frequency Operation

Thus far it has been assumed that the presently assigned frequencies would continue to be used. The DRAMA radio frequency bands are 4.4 to 5.0 GHz and 7.125 to 8.4 GHz. Here operation in the upper band will be briefly considered. For comparison purposes an 8.3 GHz transmit frequency is arbitrarily assumed.

The antenna gain at 8.3 GHz is 48.8 dB^{10} for a resultant improvement of approximately 4.4 dB for each antenna when compared to 4.9 GHz operation. On the negative side there is an additional 4.6 dB free space loss (equation 3.4). And assuming the use of EW71 waveguide, waveguide losses are approximately 0.75 dB/100 feet greater. With a total waveguide run length of 1340 feet this results in about 10 dB more waveguide loss. The other factors in equation 3.3 do not change. Summing the gains and losses results in a net value of 5.75 dB worse operation for the 8 GHz band.

In the 4 GHz band the effects of rainfall are small. In the 8 GHz band a moderate rain (.16 in/hr) results in approximately 2.3 dB and a heavy rain (.64 in/hr) results in approximately 14.3 dB additional loss when compared to 4 GHz band operation (These values were obtained by using figure 18 of reference 6). While these weather effects are not expected to be a prominent degrading factor when compared to other factors they do present some additional degradation at the higher frequency.

3.6 Conclusions

As stated in reference 3 with the system gain specified for the dual diversity (space or frequency) DRAMA radio, an LOS link of 161 km (100 miles)

should not, under normal conditions, require an antenna size greater than 4.57m (15 feet) to obtain the required link margin. However, the link under consideration is not typical. The normal waveguide loss (elliptical) in the 4 GHz band is 3 dB.³ Whereas, because of the extreme run lengths for the English Channel link, losses in excess of 15 dB have been calculated. This difference in the normal and actual values is the predominant cause of predicted link deficit.

Irrespective of which procedure is used to predict performance, a substantial deficit exists in the satisfaction of established performance criteria. The use of the DRAMA radio is a straightforward dual space or frequency diversity configuration for the English Channel link is inadequate. Frequency diversity calculations in the 4 GHz band show a smaller deficit than space diversity, but the standard procedures followed in determining the deficit are considered over-optimistic (because of the considerations identified in Section 3.3.2). Comparable performance is expected. In any event, the standard procedures still result in the prediction of substantial deficits. Use of the more recent procedures which give different performance requirements for short path (< 32 km) than long paths (≥ 32 km) result in even larger deficit predictions. At least 8dB of deficit (frequency diversity calculations) and more realistically 11 or 12 dB of deficit must be eliminated to meet availability requirements. In the 8 GHz band deficits are expected to be an additional 5.75 dB greater and atmospheric absorption weather effects will start to be a factor which indicates a change to this band should not be attempted.

SECTION 4

DRAMA RADIO SPACE/FREQUENCY QUADRUPLE DIVERSITY OPERATION

4.0 Introduction

Thus far the existing analog link configuration across the English Channel between Swingate, England and Houtem, Belgium has been described; it has been shown that a straightforward application of a dual space or frequency diversity DRAMA radio configuration on the link would not meet availability requirements, and an indication of the required degree of improvement has been obtained.

Several alternatives for reducing the deficit were considered (see Section 5) and it was concluded that additional diversity is almost dictated by link availability requirements. Since the existing link yields operationally acceptable performance, the possibility of modifying the basic analog link design approach to accommodate DRAMA equipment digital operation in a similar type of configuration was investigated.

Analysis of very preliminary DRAMA terminal design information¹² available led to the conclusion that modification of DRAMA terminals to incorporate quadruple diversity switching of the total transmitted bit streams would require major redesign problems. Because the internal time division multiplex (TDM) frame patterns for two different DRAMA radio terminals, operated in parallel with the same data, would have random phases relative to each other and would not necessarily occur in the same relative positions in the total bit streams the data from two terminals could not be aligned by the use of the internal TDM frame pattern unless special bit stream alignment procedures were incorporated at the transmitter.

Use of the internal TDM pattern would also present differential delay problems; the waveguide run lengths to the upper and lower antennas are significantly different and in excess of the present radio equalization specification. Thus even though there are no technology reasons to preclude the construction of a quadruple diversity switching digital radio of the DRAMA type, the differential equalization and data alignment design procedures would require major costly changes.

Believing, as a result of the analyses, that additional diversity is necessary and that modification of the DRAMA radio to obtain quad-diversity would be excessively costly, an effort was made to provide a method of obtaining additional diversity in a more cost effective manner. The DIDICOM applique approach described in this section resulted. From a design standpoint the applique could be operated with either space or frequency diversity DRAMA radio terminals. However, for reasons to be addressed later in the section, operation with space diversity terminals would almost universally be preferred. Consequently, the initial expository description will be restricted to such a configuration.

4.1 Description of the DIDICOM (Space Diversity Terminal)

4.1.1 Configuration Overview

The recommended system configuration, which entails a utilization of the DIDICOM, closely parallels the existing analog system. The LC-4SC¹³ microwave terminal which forms the basis of the present system consists of two active transmitters, two hot standby transmitters, and four receivers. A quad-diversity combiner is used to combine the output signals from the four receivers to arrive at the final signal. The digital system

would also utilize two active transmitters, two hot standby transmitters, and four receivers. The essential difference is the manner in which combining occurs. Each DRAMA radio terminal pair (transmit/receive) on the upper and lower antenna pairs is operated in a normal hot standby mode providing the selected demultiplexed signals from each radio. Since the selected signals out of each radio in the absence of errors provide identical sequences, data alignment of corresponding signals can be accomplished by correlation. The preferred radio's output can then be selected in the same manner in which the preferred channel is selected within the DRAMA radio. That is, for the sake of minimizing costs, the diversity selection process is done in two steps instead of one. The processing required to accomplish the interface between the multiplex (or crypo) equipment and the DRAMA radio for operating in this manner is accomplished within the DIDICOM applique device. This general DIDICOM system configuration, which does not require any DRAMA radio modifications, is illustrated in Figure 4.1.

The actual construction of the DIDICOM must take into account not only the basic digital combiner functioning but also operational aspects. As an example, since the DIDICOM will require the use of the Received Signal Level (RSL) and Signal Quality Measure (SQM) values from the radios, the Fault Alarm System (FAS) cannot use these same radio connections. Therefore, the DIDICOM must provide the RSL's and SQM's for access to the FAS or else the DIDICOM or FAS must obtain them from some internal part of the radio. The first alternative would most likely be preferred since an incorporation of all required functions into an applique device would minimize additional costly modifications to other equipments.

The remainder of this section seeks to identify the functional operation of the DIDICOM and to identify the details which must be

considered in its design and usage. There is a great deal of flexibility in actual design detail, functional modularity and system configuration. The description given is for presentation purposes only. It is intended to illustrate how a DIDICOM could be constructed and used rather than to define how it will be done, which will be a function of final specification coordination with various MIL-DEP's and the successful contractor's performance.

4.1.2 Transmission

With respect to transmission the changeover to an analogous digital operation using DRAMA radios is conceptually straightforward. But with the existing link parameters, waveguide run length differences cause a differential delay equalization complication. As discussed in Section 2.2 in the implemented design the topmost diversity antenna pairs correspond to a normal hot standby space diversity arrangement; a similar arrangement at a different frequency is used on the lower antenna pairs. Two DRAMA radio terminals tuned to different frequencies will therefore provide a comparable transmission capability.

Figure 4.2 shows the DRAMA radio set digital input/output when operating with two mission bit stream (MBS) inputs. With respect to the applique device, at the transmit side, one of the radios could be designated as master and run in the normal manner for the purpose of obtaining the transmitter clock for driving for multiplex equipments. Thus this clocking need not be changed. Since the data and timing must be applied to two radios, it is necessary to obtain duplicate copies of them. The output data and timing from the multiplex equipment would be inserted into the applique device, split and amplified to obtain the proper levels

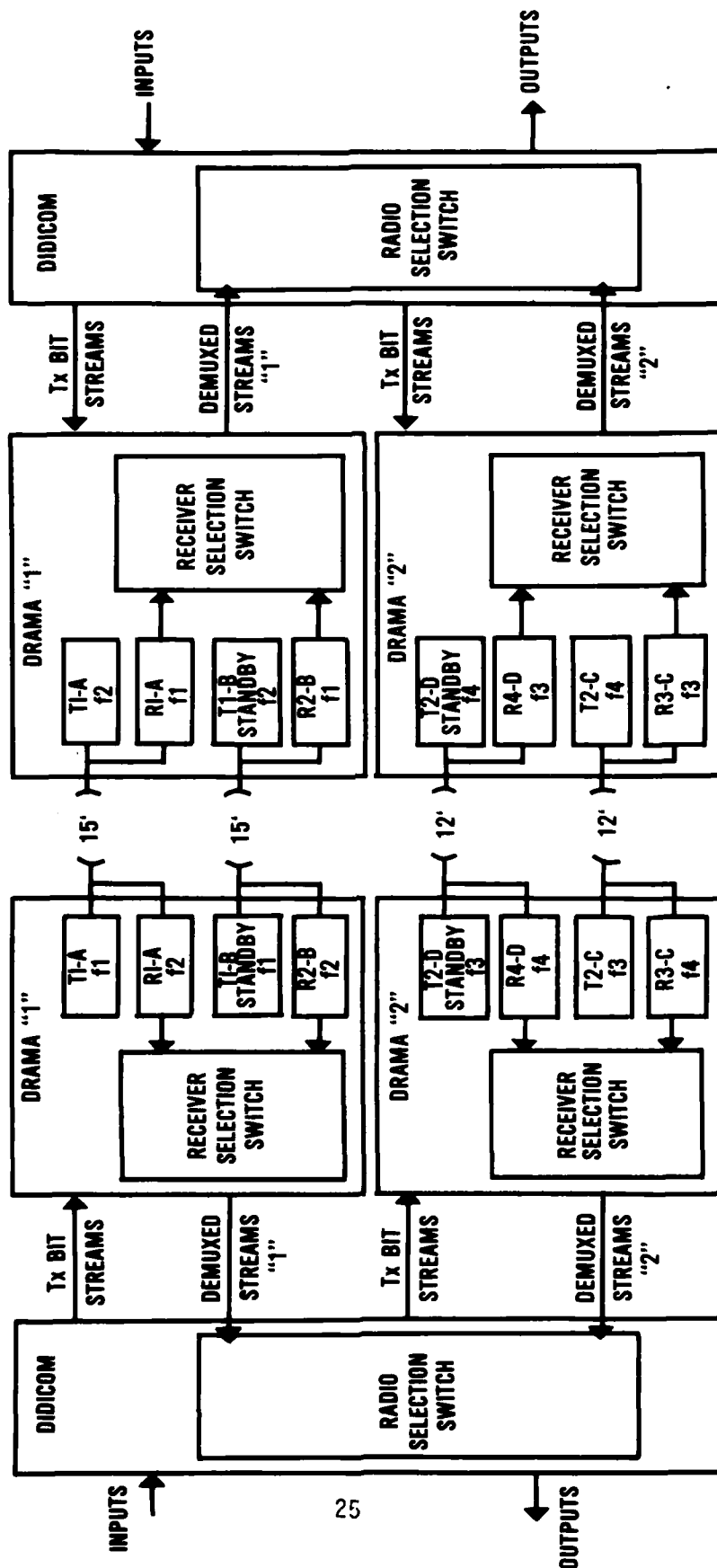


FIGURE 4.1: GENERAL DIDICOM SYSTEM CONFIGURATION

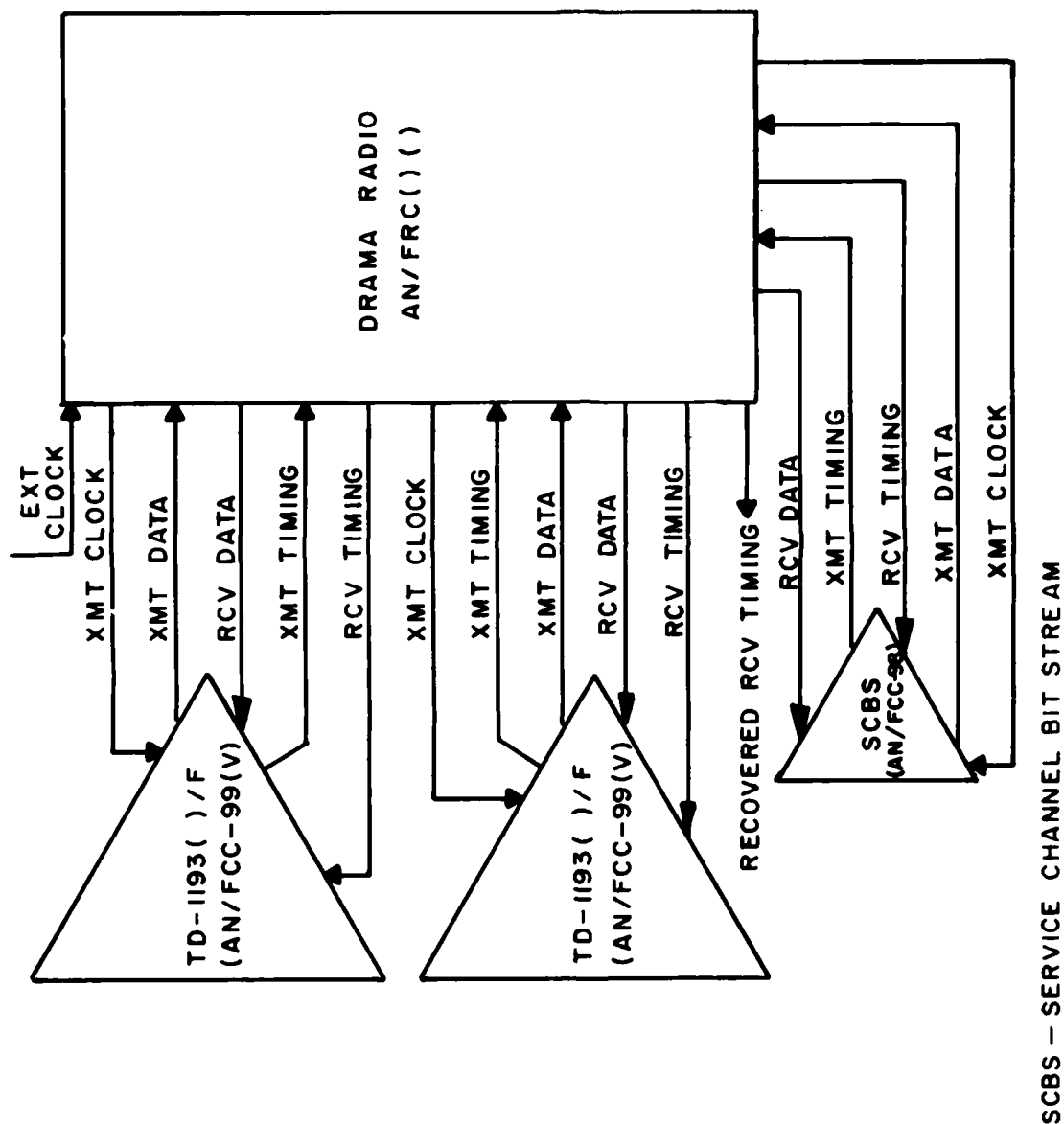


FIGURE 4.2: DRAMA RADIO SET DIGITAL INPUTS/OUTPUTS

for input into the radios. Figure 4.3 illustrates the data transfer function of the transmitter portion of the applique unit. The required characteristics of the signals leaving the applique device are identical to the requirements of the signals entering the device since they must interface the radios in the same manner as the original signals.

Table 4.1, extracted from reference 1, shows the delay line equalization used on the existing links.

TABLE 4.1: DELAY EQUALIZATION

| <u>TRANSMITTERS</u> | <u>DELAY (10^{-9} Sec) Swingate</u> | <u>DELAY (10^{-9} Sec) Houtem</u> |
|---------------------|--|--|
| Upper | 0 | 0 |
| Upper (Standby) | 45 | 45 |
| Lower (Standby) | 0 | 0 |
| Lower | 240 | 495 |
| <u>RECEIVERS</u> | | |
| Upper (A) | 0 | 0 |
| Upper (B) | 45 | 45 |
| Lower (C) | 630 | 600 |
| Lower (D) | 855 | 1125 |

There is 495 nanoseconds of transmitter and 525 nanoseconds of receiver differential delay at the lower antenna pair at Houtem: the DRAMA radio specification ¹¹ requires the capability of equalizing differential absolute delays of up to 350 nanoseconds for transmit and 350 nanoseconds for receive. Because synchronization at the receiver within each DRAMA radio is accomplished by lining up the internal TDM sync patterns, ¹² as opposed to lining up the data, the difference in delays needs to be compensated for following internal multiplexing. Therefore, a retention of the present antenna positions would necessitate a DRAMA radio modification; the delay could not be compensated for within the applique device. Fortunately, as will be discussed in Section 5.3, RSL data indicates a downward movement

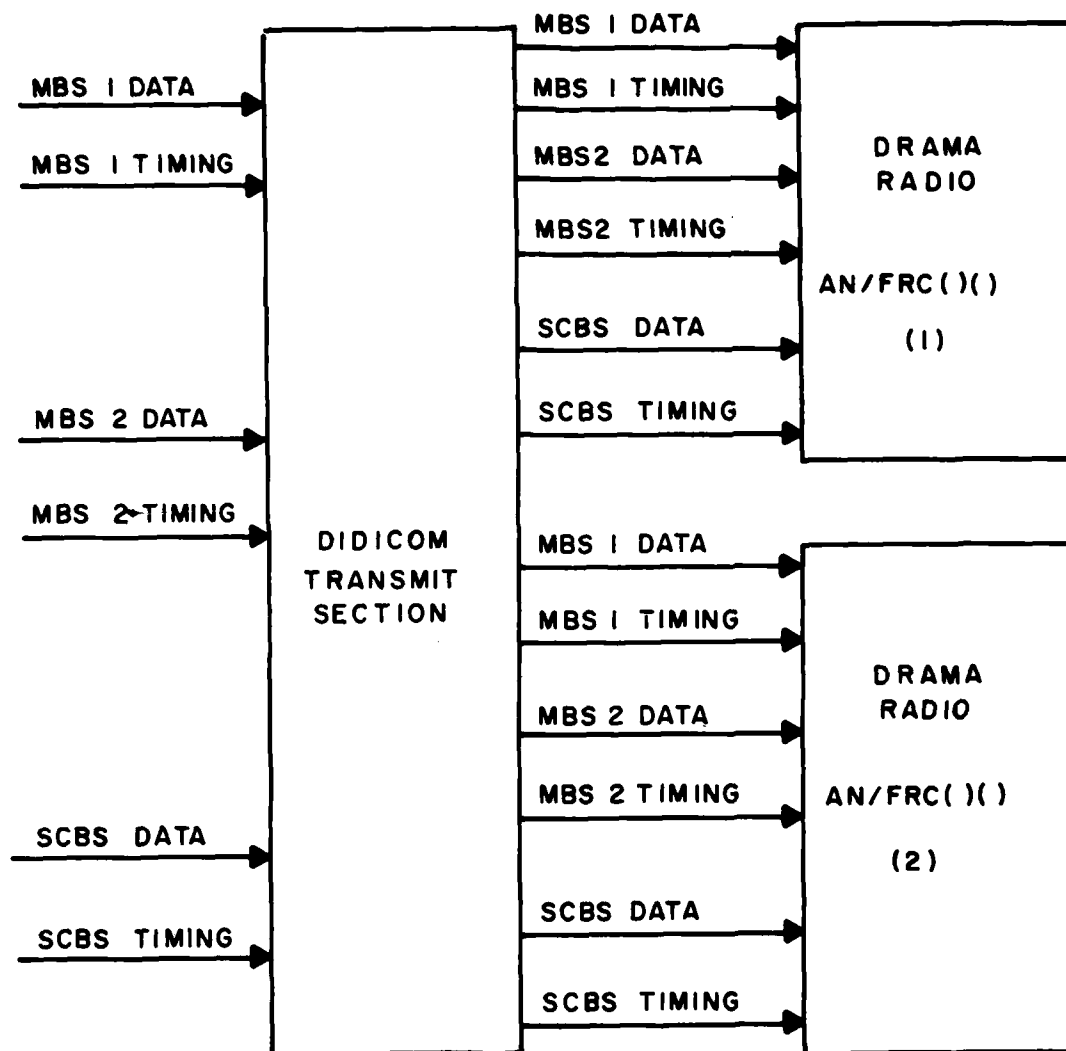


FIGURE 4.3: TRANSMITTER PORTION OF DIDICOM

of the upper of the lower two antennas at Houtem (channel D antenna) should not impair, and may well improve, performance. At the same time such action can be used to reduce the differential delay to a value which is less than the specified DRAMA value thereby removing any necessity to modify the radios. With such a movement the DIDICOM, with respect to transmission, is essentially just a collection of splitters and amplifiers to obtaining the duplicate MBS's and SCBS data and timing bit streams. Figures 4.4 and 4.5 illustrate how the DIDICOM transmitter section could be interfaced in an operational configuration. Figure 4.4 is for a radio regeneration mode such as envisioned for the English Channel link. Figure 4.5 illustrates a configuration involving crypto interfaces.

4.1.3 Reception

The movement of the antenna indicated above eliminates the requirement for radio modification of the differential delay circuitry. The DRAMA radios could then be run in a normal dual space diversity radio configuration to obtain the selected demultiplexed signals from each radio. For the moment disregarding certain operational considerations, the basic function of the receiver portion of the DIDICOM is to utilize outputs from the two dual diversity radios in selecting the preferred received versions of the MBSs and SCBS and provide them in the proper form to the appropriate interfacing equipments without loss of BCI.

Figure 4.6 illustrates the receiver data flow process. Each of the DIDICOM inputs are specified DRAMA outputs. ¹⁵ The various RSL and SQM analog values (and probably the on-line receiver indicators) will provide information for selecting which radio receiver outputs are to be used. If the radio provided a single on-line RSL output and a single on-line SQM

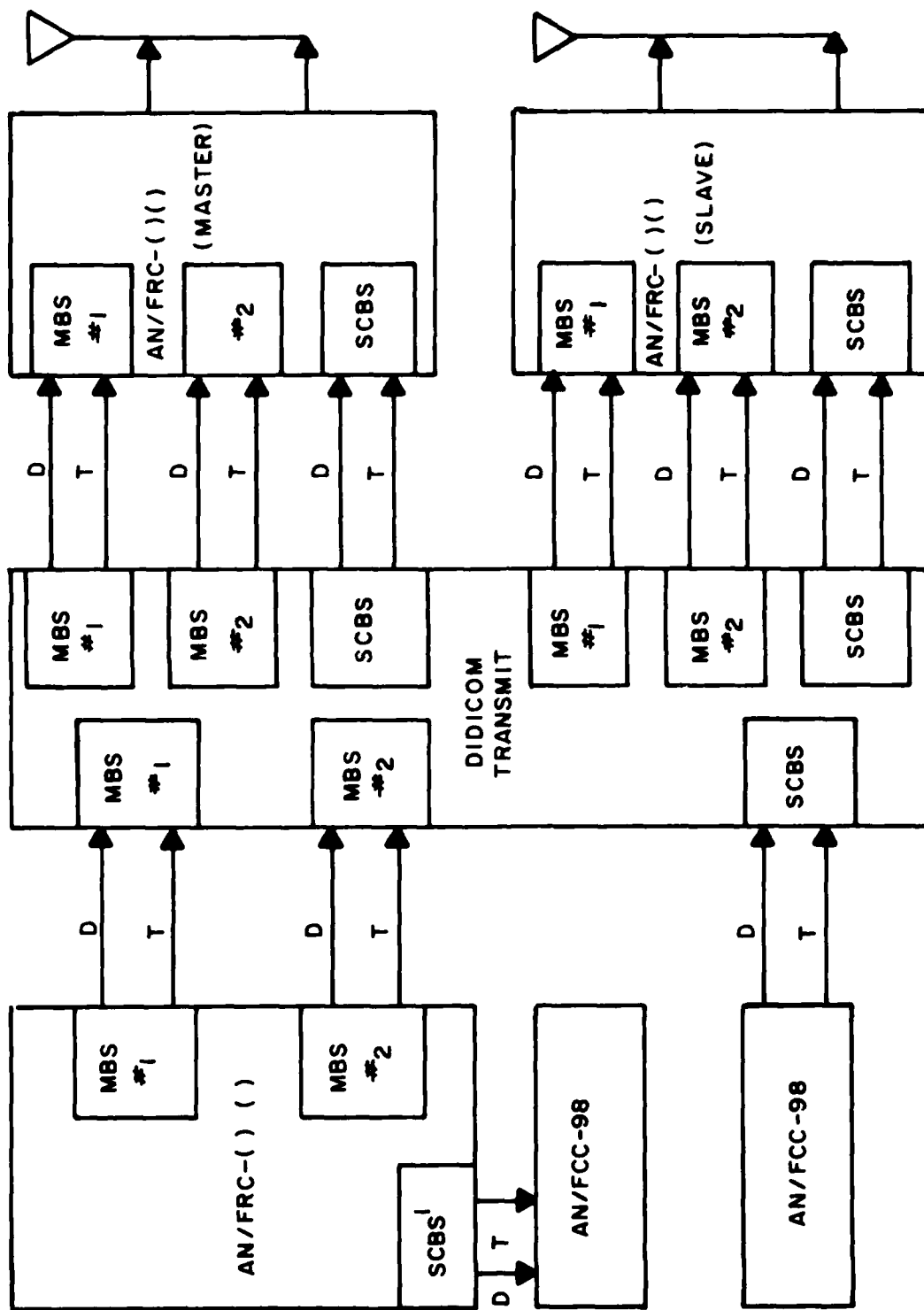


FIGURE 4.4: DIDICOM TRANSMIT DIGITAL INPUT/OUTPUT PORTS (RADIO REGENERATION)

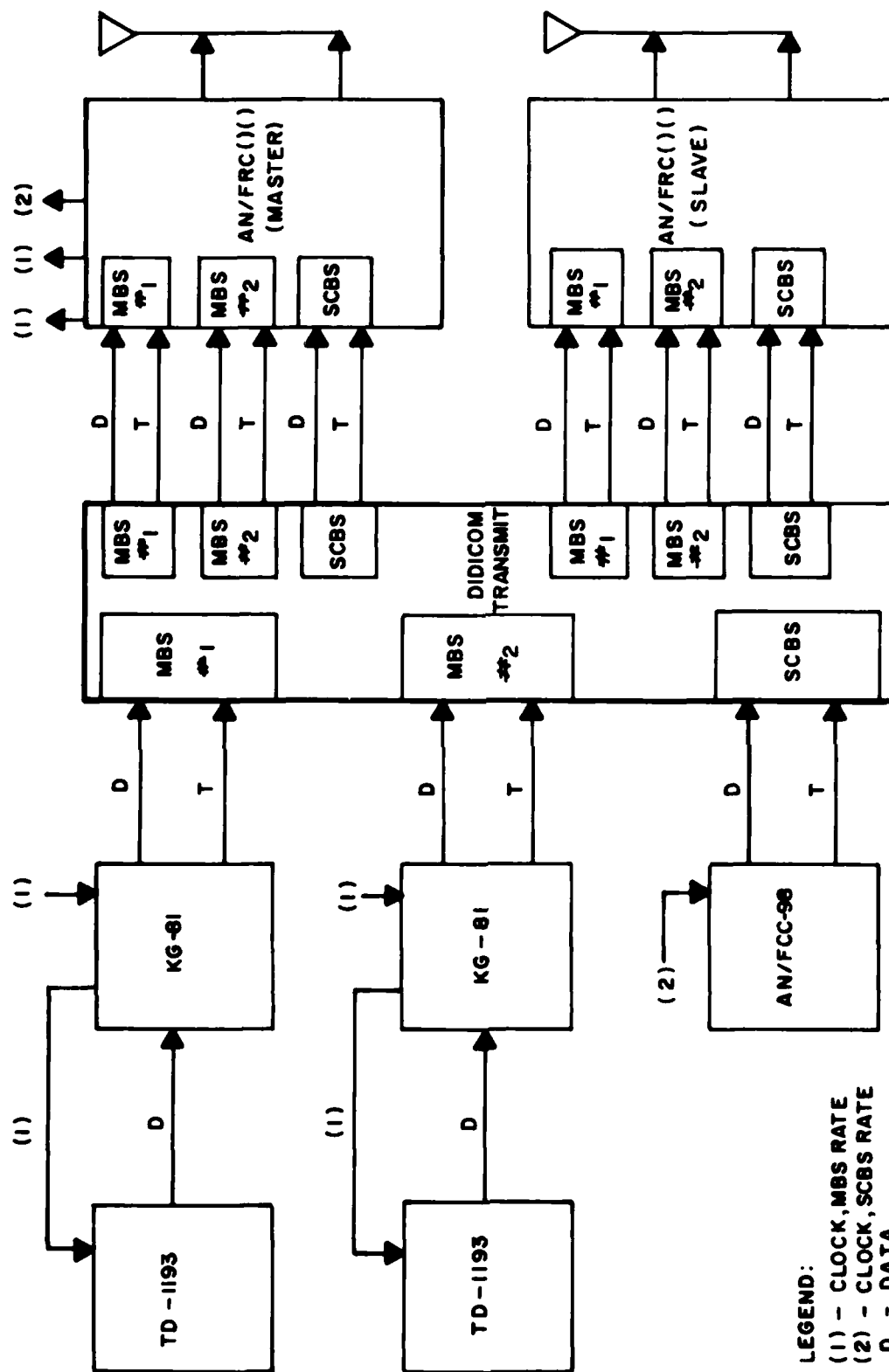


FIGURE 4.5: DIDICOM TRANSMIT DIGITAL INPUT/OUTPUT PORTS (KG-81 INTERFACE)

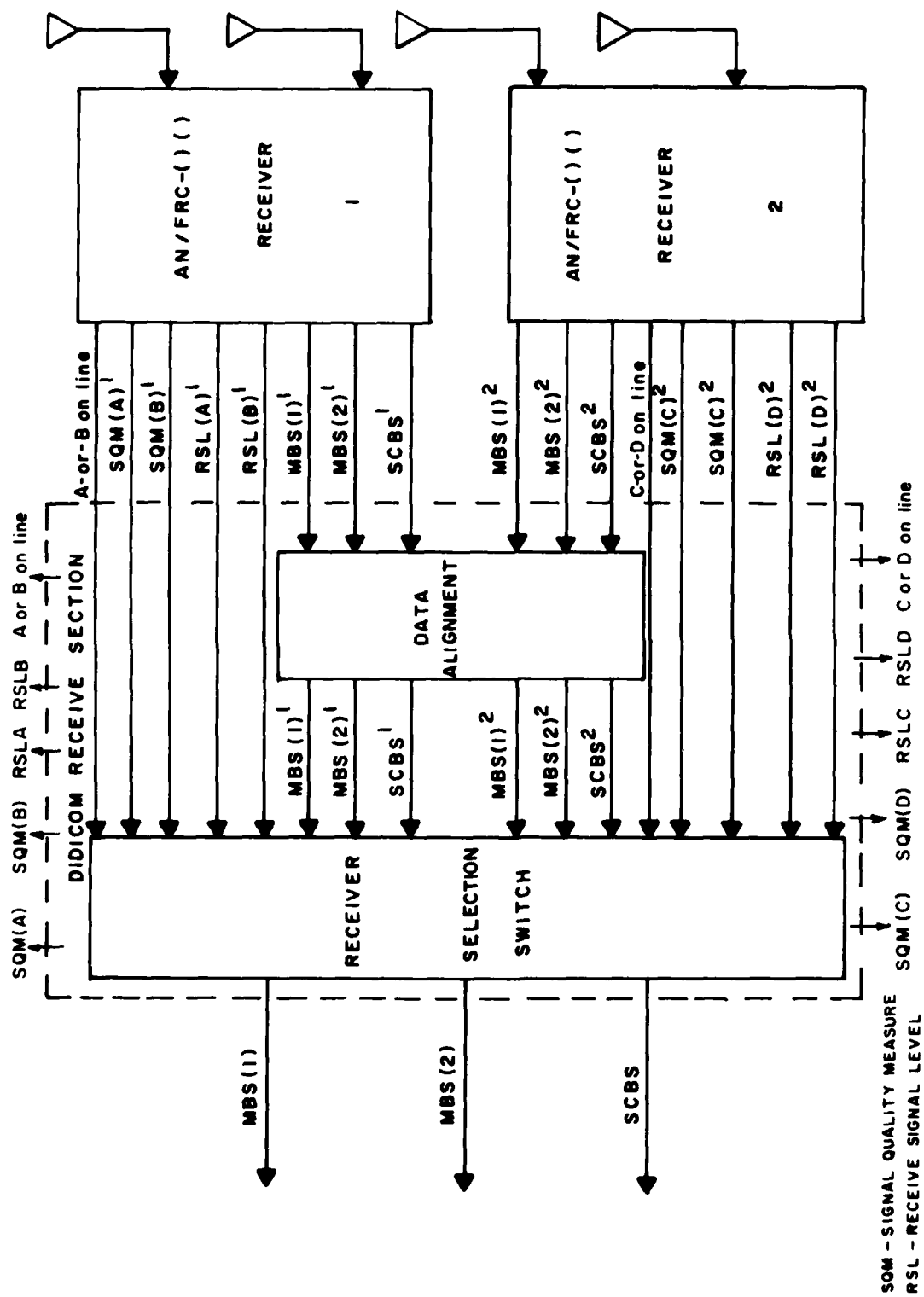


FIGURE 4.6: DIDICOM SIGNAL FLOW DIAGRAM

output for each of the receivers it would not be necessary to provide the individual outputs for each received channel. However, the DRAMA radio does not. The first step within the receiver selection switch would most likely be the provision of a switch to select the on-line RSL and SQM for each radio receiver. Once this is done, selection of which radio receiver is preferable could be accomplished using the same selection circuitry as is used within the DRAMA radio for determining which channel is used.

The importance of maintaining a small switch hysteresis has already been addressed in Section 3. Because of the more significant variability expected on the English Channel link in comparison to a typical dual diversity link, a small hysteresis becomes even more critical.

The antenna movement removes the necessity to modify the DRAMA radios absolute delay provisions. However, the absolute path delays over the two radio pairs will differ significantly because of the waveguide length differences. There will be a time difference in the outputs from the radios shown in Figure 4.6. Furthermore, since the multiplex data has already been removed the data cannot be aligned as it was within the radios. The applique device must contain the capability of aligning the corresponding bit streams of the two radios and perform switching without loss of BCI based upon the signal quality indicators. Because in the absence of errors the corresponding data sequences are identical, correlation can be used to line up the sequences. This can be done using only one sequence pair and then using the same time delay for the other pairs or by separately correlating on each pair. To remove the requirement of searching over a number of bits for correlation a fixed but variable

absolute delay capability for the timewise leading sequences would seem advisable, then the search could be limited to at most a few bit times.

Using Table 4.1, the maximum total equalization for the existing link is 1350 nanoseconds (495 + 855). By providing a capability to compensate for up to 1500 nanoseconds of fixed delay, sufficient margin for antenna movement and equipment delay differences would exist. With such equalization capability it would only be necessary to provide for delay variations around the fixed delay. The results presented in reference 7 indicate such variation can be quite large. At a MBS rate of 12.928 MBPS 500 nanoseconds is less than 7 bits. Provision for up to 500 nanoseconds (in either direction) variation then would require correlation over only 15 relative positions. Thus correlation alignment could easily be accomplished. The length of the correlation registers and criteria for operation in a quite high error rate condition need to be defined but should present little problem, particularly if a continuous correlation process is maintained.

Figures 4.7 and 4.8 show the DIDICOM receive portion digital input/output interfaces for operational configurations corresponding respectively to transmit Figures 4.4 and 4.5. Not shown are the RSL, SQM and on-line receiver indicators needed for switching and for the FAS equipment as shown in Figure 4.6.

4.2 Other DIDICOM Configurations

Certain MIL DEP reviewers of the draft DIDICOM specification suggested configurations other than the use of dual space/frequency diversity as described. One suggestion was to use dual frequency terminals with maximum antenna separation to obtain space diversity

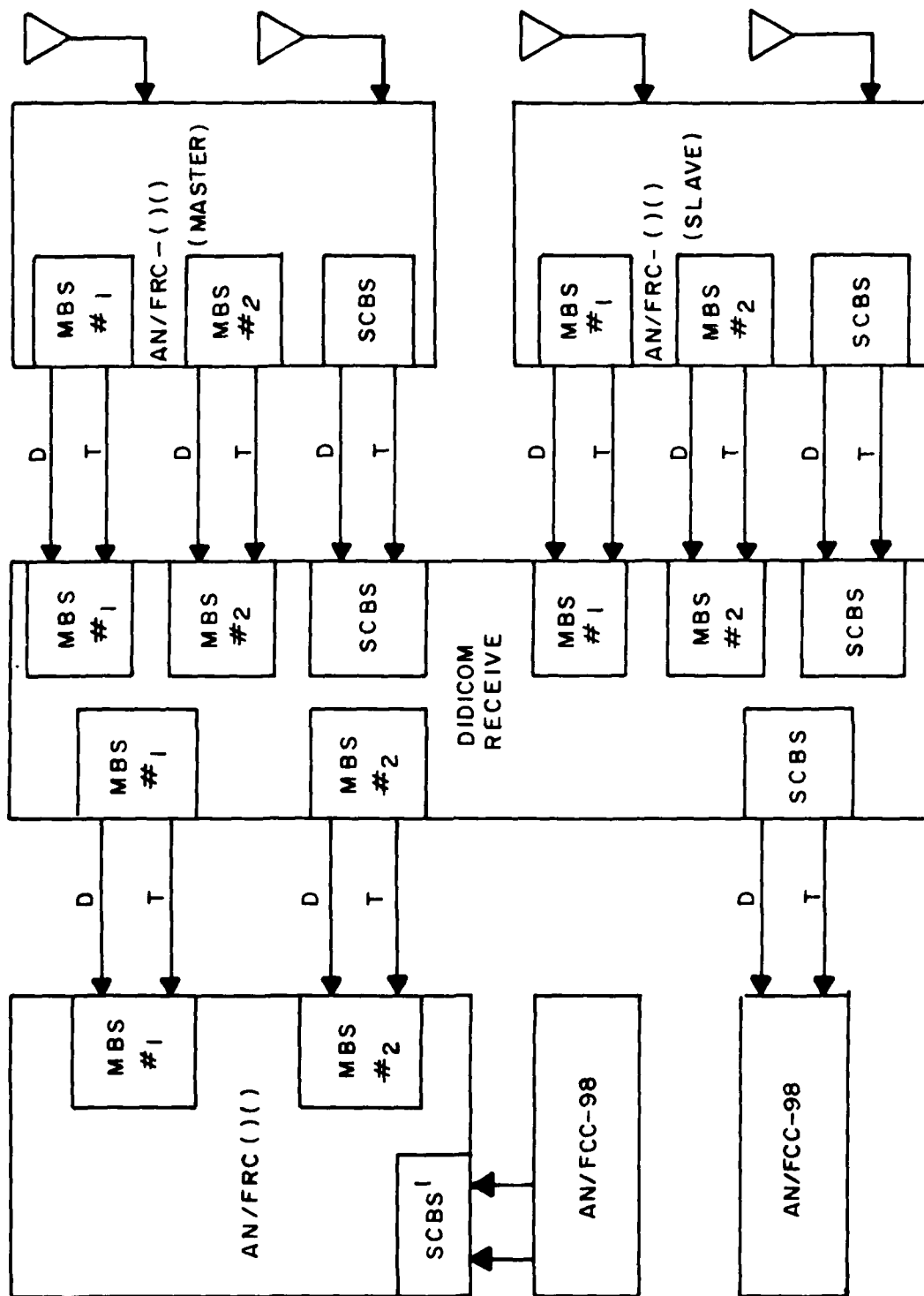


FIGURE 4.7: DIDICOM RECEIVE DIGITAL INPUT/OUTPUT PORTS (RADIO REGENERATION)

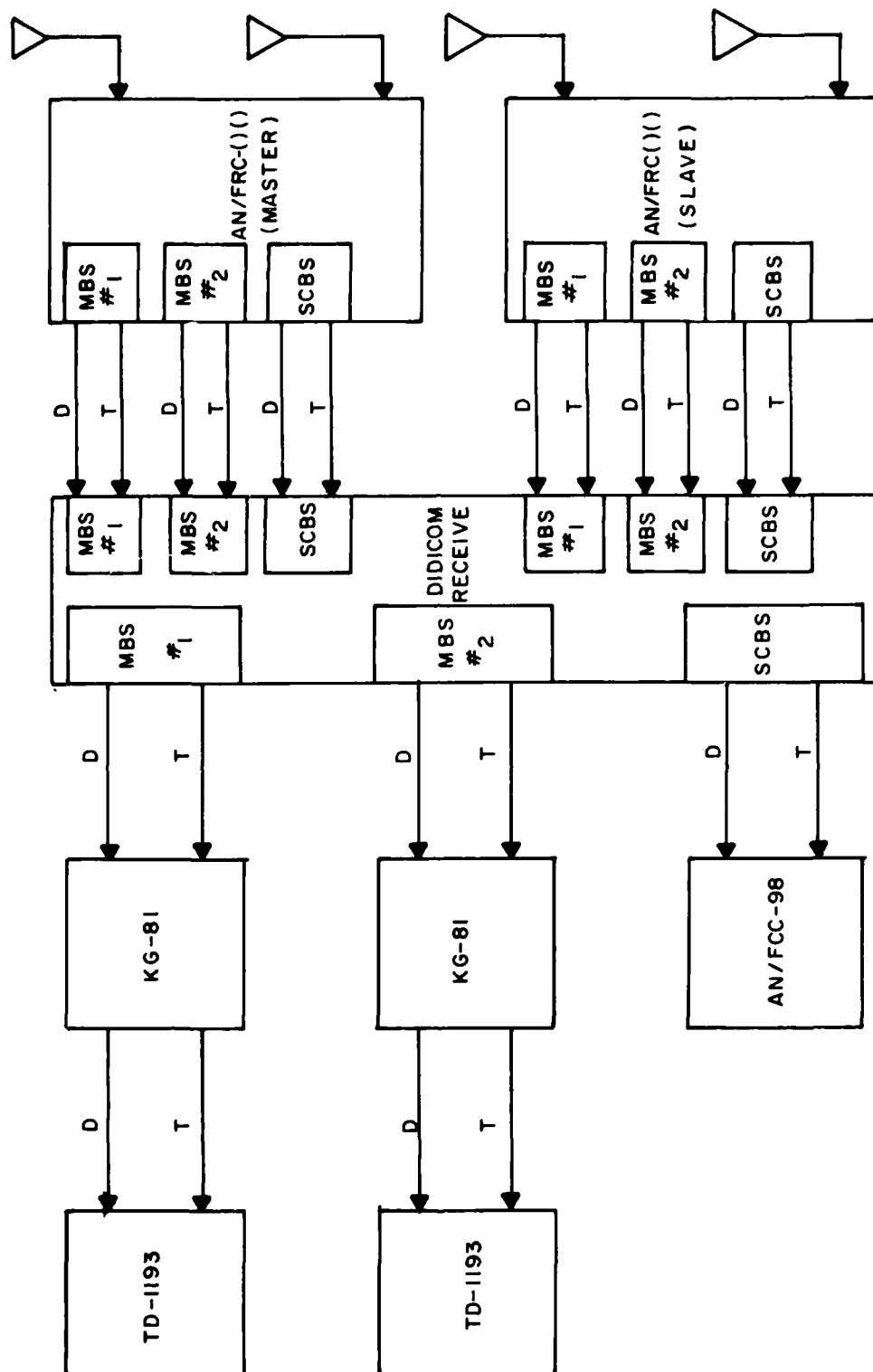


FIGURE 4.8: DIDICOM RECEIVE DIGITAL INPUT/OUTPUT PORTS (KG-81 INTERFACE)

improvement also. Such a configuration would reduce the antenna requirement and thereby also reduce tower loading. Even if the separations at Houtem are considered there can be only about a 200 meter separation of antennas (Swingate's maximum separation is less than 100 meters). For an 88 kilometer path the "wrong antenna" is only about .13 degrees off the main axis. At such an angle with the antenna beam widths there will be sufficient power to cause severe interference. If frequency diversity were used, it would be necessary to use four distinct frequencies to prevent a self-jamming of the system. The difficulty with that is frequency authorizations. Space diversity throughout was also suggested. The same self-jamming problems arise.

In the viewpoint of economics, one final suggestion was made. If a frequency diversity terminal were used at the transmit side along with suitable RF antenna switching a comparable transmission capability could be obtained as would be present in the recommended DIDICOM configuration. The difficulty here resides in the fact that the most likely occurrence of a failure is in the transmitter RF portion, most notably in the TWT. This suggested configuration has no redundancy for this circuitry and consequently should it fail, particularly on the upper antenna, availability will not be met.

4.3 Additional Operational Consideration

The basic recommended DIDICOM configuration and the necessity of providing interface capability to FAS equipment has been discussed. One additional factor needs to be considered. Because of availability requirements redundancy is often used. There is sometimes an alternative, that of equipment bypass. It is felt that the DIDICOM functions are

uncomplicated and so such equipment can be made to be highly reliable. Provided equipment repair is accomplished within a reasonable period the possibility of a DIDICOM failure corresponding to a time when the lower diversity pair is required is considered quite small. Therefore, by providing for automatic bypass of the DIDICOM transmitter or receiver in the event of a loss of any MBS or SCBS output when the corresponding inputs are present protection against DIDICOM failure is provided. Such bypass would automatically switch to the primary transmit or receive radio. That is, the radio corresponding to the upper antenna pairs would be used and until repair is accomplished the link would be operating as a dual diversity DRAMA radio terminal.

SECTION 5

DIDICOM PERFORMANCE

5.0 Introduction

Since the DRAMA radio has yet to be completed the prediction of performance is of necessity speculative. The prediction of performance for a "DIDICOM implemented English Channel link" must be even more speculative since it entails DRAMA radio terminals and propagation conditions that are not well-understood. The theoretical basis for an analytical prediction of performance for such a configuration is unavailable: the correlation of fading between the upper and lower paths is not known to the degree required. Likewise available test data is not of the proper form to guarantee the satisfaction of performance criteria. Nonetheless, before proceeding to implement a DIDICOM there should be a reasonable certainty that it will perform satisfactorily. It is also important to establish that other possible approaches will not provide sufficient improvements at lower costs. In this section extrapolation of data taken on the present analog system will be used to establish the high probability of meeting performance requirements via a DIDICOM approach. Other possible approaches will also be identified and reasons for accepting the DIDICOM approach in lieu of the alternatives will be presented.

5.1 Performance Based Upon Reference 1 Data

In Section 3 it was established, based upon established prediction procedures, that dual diversity DRAMA operation cannot satisfy performance requirements. Link testing of the analog system to determine the effectiveness of the path design was conducted from October 1973 to April 1974: the overall findings of the testing are summarized in

reference 1. The observations of importance to this report are:

(1) There were periods when at least one of the lower antennas was receiving a strong signal, the upper pair was disturbed and did not contribute to the composite output signal. At this time a low level duct provided the main signal path.

(2) The distributions of carrier levels proved the existence of a much higher incidence of ducting and super-refraction than the average predictions for Maritime Temperature Oversea paths.

(3) Outages experienced on the path will be substantially less than the outages which would occur when only one set of two antennas in a space diversity configuration is used. Taken as a whole, the results verify that the implemented quadruple space/frequency diversity system provides an effective arrangement for analog microwave transmission over long LOS paths in areas of high ducting and subrefraction where conventional techniques will not yield reliable communications. The fact that the DRAMA radio is digital in contradistinction to analog for the existing Scope Communication System has little effect on the overall conclusions since operation in either system is dependent upon the existence of an effective propagation media. Thus, from the results of reference 1, it is known that a DIDICOM implementation on the English Channel link would significantly improve performance. What cannot be substantiated from the data of reference 1 is whether the improvement would be sufficient enough to satisfy the established performance criteria.

5.2 Performance Based on AFCS Test Data

To provide more engineering detail on the existing FDM/FM system, AFCS conducted a test program to measure RSL's in the Houtem to Swingate

direction from July 1974 to May 1975. Measurements included both strip chart recordings and automatic measurement equipment implemented by the Institute of Telecommunications Sciences (ITS). The unpublished relevant AFCS findings and conclusions, based upon 159 days of useful data recorded during the test period, are as follows:

(1) Usually channels A and B (See Figure 2.2 for channel identification) carried traffic, however, there was a total of 396 minutes during the 159 days of data when channel C or D's RSL exceeded that of Channels A and B. Channel C's RSL exceeded that of all other channels for 261 minutes and channel D's RSL exceeded all other channels for 135 minutes.

(2) When channel D's RSL exceeded all other channels their RSL was also large. Whereas there were modes during which channel C's RSL was large and channels A and B had small RSL's. Channel C was required to carry the traffic for 2 minutes and 4 seconds.

(3) While channel D was never required for traffic, elimination of channel D cannot be justified from this information alone. For example, if channel C is down due to equipment failure, channel D may be necessary. In any event, more information is needed especially during extreme refractive conditions such as reportedly occurred at Feldsburg/Adenau for 52 hours in October 1975. The elimination of channel D could only be recommended after a thorough evaluation of reactions to a multitude of various conditions.

The AFCS results indicate that the lower antennas were useful only two minutes and 4 seconds out of 159 days or by extrapolation 4 minutes and 45 seconds per year. However, this is for an FDM/FM system where threshold is -79 dBm. The data must be considered from the digital

availability standpoint.

In Section 3 it was established that the specification requires a bit error rate of less than or equal to: (a) 5×10^{-9} at an RSL of -66.8 dBm, (b) 5×10^{-2} at an RSL of -73.8 dBm and (c) by linear interpolation, 1×10^{-4} at an RSL of -72.3 dBm. The 10^{-4} bit error rate corresponds to a media availability requirement of .9999965 (DCEC-TR-12-76, Reference 2) and 5×10^{-9} bit error rate corresponds to the prior media availability requirement of .99999 (DCEC-TR-3-74, Reference 14).

A consideration of the data must also account for power differences. The DRAMA radio is specified to operate at 33 dBm, whereas the test data was obtained with a transmitter power of 6.5 watts or 38.1 dBm. The link test data consequently should be translated by 5.1 dBm. The data presented in the remainder of the report has been adjusted to correspond to the DRAMA power level.

5.2.1 Overview of Raw Data Observations

Observation of the raw data reveals in excess of 24 minutes where channels A and B are both below -66.8 dBm while either channel C or D is above the -66.8 dBm value. There is in excess of 14 minutes where similar conditions occur for an RSL value of -72.3 dBm. These times, if there were no further outages would result in dual diversity availabilities for the 5×10^{-9} and 10^{-4} error rates of .999895 and .999939, respectively, during the 159 days the data was accumulated. There were no observed times when all 4 channels were below the indicated RSL's. Thus, the data substantiates the conclusion arrived at in Section 3 that dual diversity DRAMA operation would be inadequate and verifies that the suggested DIDICOM

implementation would result in substantial improvement.

5.2.2 Processed Data Results

The ITS measurement equipment measures the RSL on each channel each 1/10 second. It preprocesses the data in a minicomputer and places the results on magnetic tape for post processing. While the processing was not programmed to provide the specific data required to evaluate the DIDICOM it does provide some very relevant results.

Figure 5.1, taken from the unpublished AFCS report, presents the Rayleigh curve fit for all data points from the July 1974 test start through 31 Dec 1974 or 2666 hours. It shows a DRAMA adjusted RSL of -63.1 dBm for an availability of .9999 for the combined output.

Figure 5.2 and Table 5.1, which were extracted from data provided by ITS, show the performance obtained during the July 1974 to May 1975 test period. The points represent 3646 hours of data with 10 measurements per second. Consequently, there were 1.31256×10^8 samples. This represents all the data considered useful during the test period. This data shows the .9999965 availability occurs at about -68 dBm for the combined output or about 4 dB more than the required -72.3 dBm value. The .99999 point occurs at just about the required -66.8 dBm RSL value. It is therefore concluded that a DIDICOM applique unit would permit the satisfaction of the availability criterion of DCEC-TR-12-76 and probably also the criterion of DCEC-TR-3-74 since there should be some design margin in the DRAMA implementation.

5.3 Antenna D Movement

As discussed in Section 4, it is necessary to reduce the differential delay on the lower antenna pair at Houtem or modify the DRAMA radio. The

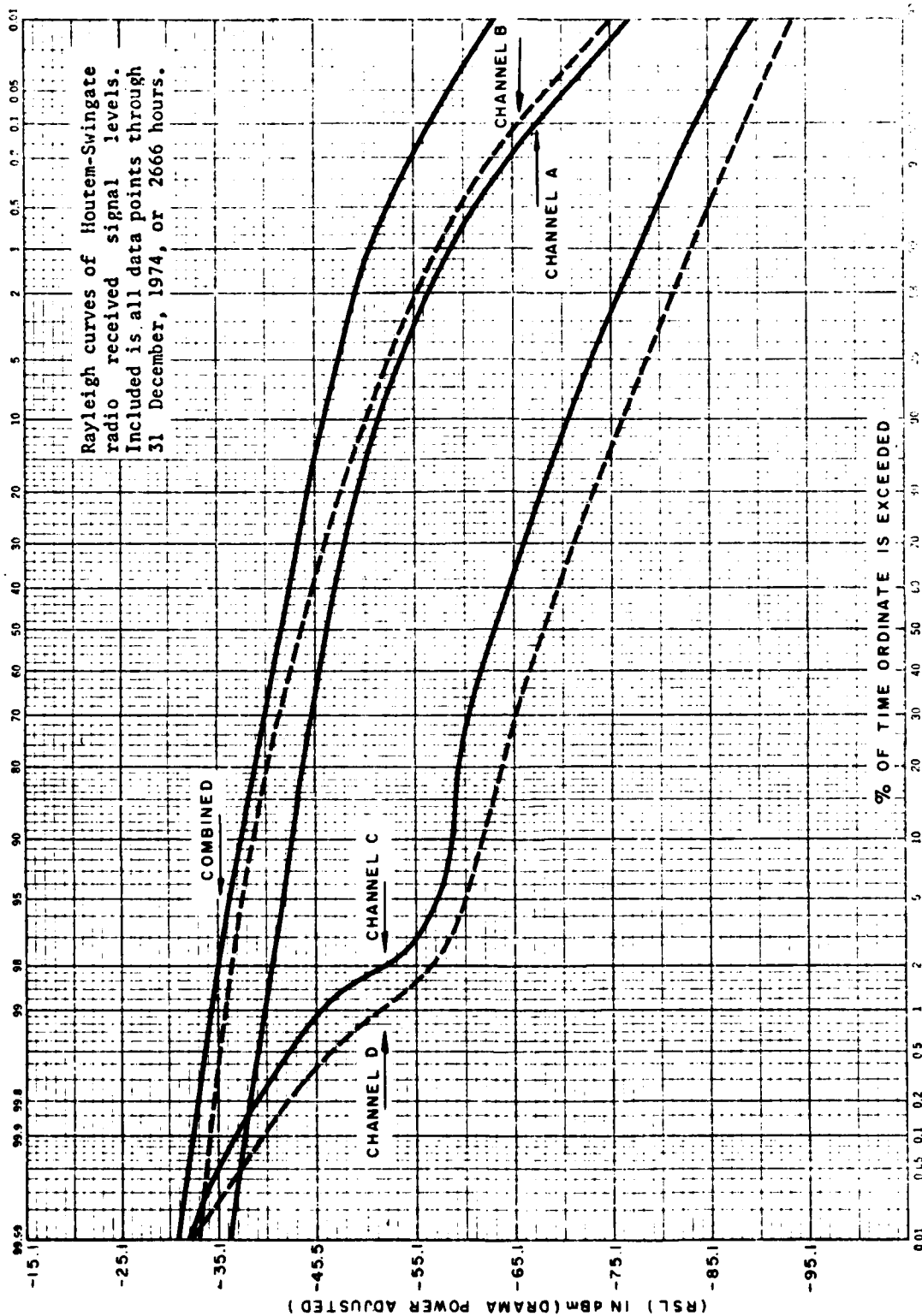


FIGURE 5.1: RSL DISTRIBUTIONS THROUGH 31 DECEMBER 1974

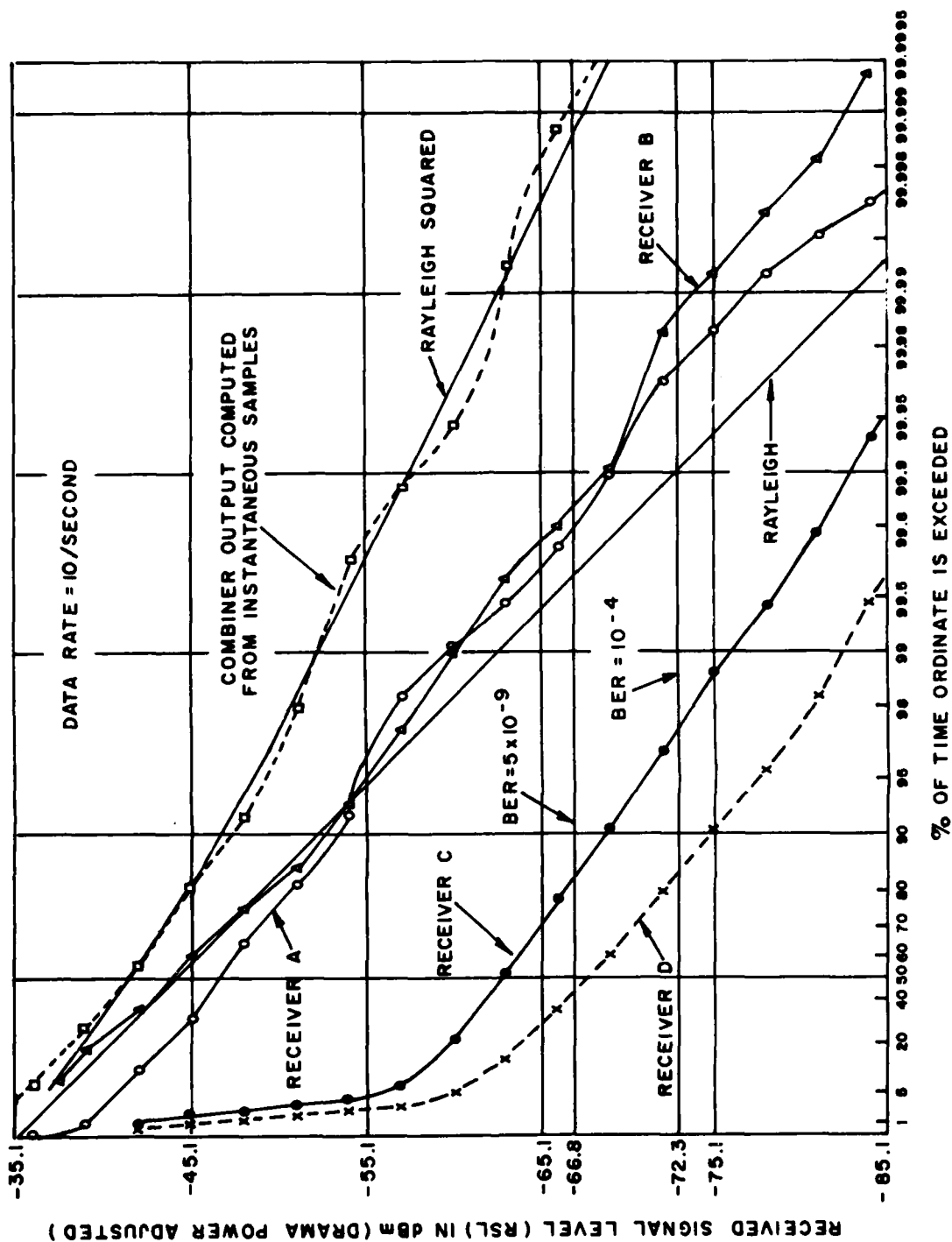


FIGURE 5.2: RSL DISTRIBUTIONS OF ALL DATA

| RSL (DBM) | REC A | REC B | REC C | REC D | COMBINED |
|-----------|---------|---------|---------|---------|----------|
| -57.1 | .983270 | .972041 | .069832 | .034270 | .998767 |
| -60.1 | .990620 | .990090 | .223375 | .052683 | .999435 |
| -63.1 | .994732 | .996132 | .538598 | .155372 | .999930 |
| -66.1 | .997501 | .998081 | .786008 | .370798 | .999987 |
| -69.1 | .999001 | .999059 | .906233 | .608045 | .999998 |
| -72.1 | .999711 | .999841 | .965025 | .808225 | .999999 |
| -75.1 | .999842 | .999922 | .985506 | .908082 | .999999 |
| -78.1 | .999921 | .999964 | .994479 | .956413 | .999999 |
| -81.1 | .999951 | .999984 | .997994 | .982730 | .999999 |
| -84.1 | .999967 | .999994 | .999389 | .994918 | .999999 |

TABLE 5.1: FRACTION OF TIME A RSL LEVEL IS EXCEEDED (DRAMA POWER ADJUSTED)

above data indicates that channel D was never required to carry traffic since whenever channel D's RSL exceeded the other channels, their RSL was also large. However, there were times during which channel C's RSL was large and both channel A and B had small RSL's. Thus channel C is the primary channel on the lower paths. Therefore, a downward movement of the channel D antenna should not have any deleterious affect on availability and might even improve conditions. The movement should be large enough to bring the differential delay on the two channels within the DRAMA specification requirement.

5.4 Data Alignment and Switching

Each DRAMA radio pair has provisions for performing diversity switching without loss of BCI. It is also necessary to provide BCI when using the DIDICOM. These provisions are covered under the DIDICOM description. The effectiveness of the provisions, however, is dependent upon the availability of reliable bit streams out of both DRAMA radio terminals. By interpolation from the DRAMA specification, the probability of error for an RSL of -72.3 dBm is $\leq 10^{-4}$. From Figure 5.2 this RSL occurs approximately 97% of the time on channel C. While no data is of a form for determining the dual diversity availability on the lower channels, the availability certainly can be no worse than channel C's 97% availability which implies there should be little difficulty in performing data alignments to maintain BCI during DIDICOM switching. The specified performance is a worst case condition predicated on the DRAMA contractor just meeting requirements. Good engineering practice would dictate that the specification be satisfied with some margin. Such a situation can only improve conditions.

5.5 Other Approaches

As indicated by the prior discussions the "DIDICOM" approach is well within the state-of-the-art and should not present any major development problems. Nonetheless, as with any new low production device, its unit cost can be expected to be quite high. In spite of this, it is believed to be the most economical method of satisfying link availability requirements.

Before arriving at the "DIDICOM" approach, other possibilities were investigated. When analysis indicates extra system gain is required, relatively inexpensive amplifier associated solutions are usually the first techniques to be employed. Among such possibilities are the employment of low noise preamplifiers, tower mounting of preamplifiers (possibly low noise), tower mounting of terminals and RF power amplification. Additional diversity, which is the basis for the DIDICOM and the present English Channel link implementation, is also widely used.

5.5.1 Low Noise Preamplifiers

According to reference 12 a noise figure of less than 10 dB will be achieved at the antenna terminal for both DRAMA diversity configurations. The design entails the use of a double balanced mixer and low noise IF preamplifier integral assembly which provides a noise figure of less than 7.5 dB. Preamplifier substitution would have to provide a lower value to be of benefit. Highly ruggedized ambient temperature compensated low noise preamplifiers in the 4 GHz band by themselves have a noise figure in the 4.5 to 6 dB range. Hence preamplifier substitution would yield less than 3 dB benefit.

5.5.2 Tower Mounting of Preamplifiers

A major factor contributing to the deficit with dual diversity

operation is the 494 feet and 846 feet of waveguide at the two sites. Tower mounting of the preamplifiers would eliminate the waveguide loss associated with the receive side. This would result in a savings of 5.6 dB (494 feet times 1.13 dB per 100 feet) for the Houtem to Swingate link and 9.8 dB (846 feet times 1.16 dB per 100 feet) for the reverse direction. Tower mounting if utilized with substitute lower noise preamplifiers potentially could result in about 8dB improvement in the Houtem to Swingate direction and about 12 dB in the reverse direction. Such a solution by itself would not provide enough extra system gain in the Houtem to Swingate direction and operation in the reverse direction would be marginal.

The approach of tower mounting of amplifiers is technically feasible but care would be required to insure mechanical problems with tower loadings did not cause problems. The approach would require a change in the radio preamplifiers arrangement. Heat would have to be provided near the top of the tower and it may well be necessary to use a redundant preamplifier configuration because of maintenance difficulties should a problem occur. Tower mounting would entail a continuing maintenance problem.

Summarizing tower mounting of preamplifiers is a technically feasible method of obtaining rather significant improvements but does not provide all the gain required and would present maintenance problems; it is not in itself an acceptable solution.

5.5.3 RF Power Amplification

Amplification above the 33 dBm specified power level is not a viable approach since little to no power margin exists at this level for

the DRAMA radio.

5.5.4 Terminal Tower Mounting

The possibility of tower mounting of the entire DRAMA radio terminals has been considered. The maximum cable length that can be used from the TD-1193 to the DRAMA radio is about 390 feet.¹⁵ Equating this with the replacement of 780 total feet of waveguide (twice 390) about 9 dB system gain could be obtained. Looked at another way, terminal tower mounting would still require 456 feet of waveguide at Houtem and 104 feet at Swingate unless the multiplex equipment was also located on the towers. A deficit would remain unless some other means of reducing the deficit were employed. Tower mounting of low noise preamplifiers as discussed above could be used in conjunction with the terminal mounting but such an arrangement would yield marginal performance and is not recommended because of mechanical complexity, maintenance difficulties and most likely tower loading problems.

5.5.5 Additional Diversity

Since the DRAMA radio contains no provisions for in excess of dual diversity, there was an original reluctance to recommend the use of increased diversity. However, as discussed above, the alternatives considered all have rather significant drawbacks. Of the approaches investigated, additional diversity is concluded to be the only viable method of obtaining the improvements required to satisfy established availability requirements.

The existing link utilizes the LC-4SC quadruple diversity FM radio equipment with quadruple input maximal ratio squared combining. To provide a directly analogous full quadruple diversity arrangement

would be exorbitantly expensive because of major redesign of the radio necessitated by synchronization considerations identified in Section 4. The "DIDICOM" approach utilizes the individual multiplexers' data streams for synchronization as opposed to the radio's internal Time Division Multiplex framing pattern to obtain final synchronization and thereby eliminates the difficulties which would occur in a full quadruple diversity implementation using internal TDM framing patterns. Overall complexity is significantly less than would be present in a conventional quadruple diversity implementation. While the conventional approach has some theoretical advantages over the "DIDICOM," practically the performance of the two systems should essentially be the same.

5.6 Summary and Conclusions

DEB connectivity consists mostly of tandem operation: poor performance on any one link can impose problems at many sites. The Houtem-Swingate link provides 384 channel connectivity between Belgium and England sites. Therefore, it is essential that availability criteria be met. From the analyses and data presented in this report, it is clear that there is no way a straightforward use of dual diversity DRAMA terminals can satisfy these criteria. Some method must be employed to increase availability.

The alternatives addressed in this study, with the exception of the DIDICOM approach, all suffer from some drawback. The link geometry and propagation media almost dictate the use of additional diversity. The DIDICOM applique approach provides a method of obtaining a form of quadruple diversity which should satisfy availability criteria and which does not entail any significant implementation technology difficulties.

It is well within the state-of-the-art. A draft performance specification for the DIDICOM has been prepared and delivered to the DEB SPO. It is anticipated that this solution will be implemented on the English Channel link as part of the DEB Stage III implementation phase.

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